EPHEMERIS.

M.	t—T.	t.	θ	ρ	M.	t—T.	t.	θ	ρ
°	y		°	″	°	y		°	″
0	0.000	1901.180	201.8	0.12	190	3.008	1898.488	22.9	0.38
10	0.158	.338	192.0	0.10	200	3.167	.647	21.9	0.38
20	0.317	.497	170.6	0.07	210	3.325	.805	20.9	0.37
30	0.475	.655	118.5	0.05	220	3.483	.963	19.8	0.36
40	0.633	.813	71.4	0.07	230	3.642	1899.122	18.7	0.34
50	0.792	.972	53.6	0.11	240	3.800	.280	17.5	0.33
60	0.950	1902.130	45.4	0.15	250	3.958	.438	16.0	0.31
70	1.108	.288	40.6	0.19	260	4.117	.597	14.4	0.28
80	1.267	.447	37.4	0.23	270	4.275	.755	12.4	0.25
90	1.425	.605	35.0	0.26	280	4.433	.913	9.9	0.22
100	1.583	.763	33.1	0.29	290	4.592	1900.072	6.5	0.19
110	1.742	.922	31.5	0.31	300	4.750	.230	1.3	0.15
120	1.900	1903.080	30.1	0.33	310	4.908	.388	352.3	0.11
130	2.058	.238	28.9	0.35	320	5.067	.547	332.3	0.07
140	2.217	.397	27.8	0.36	330	5.225	.705	282.3	0.05
150	2.375	.555	26.7	0.37	340	5.383	.963	235.1	0.07
160	2.533	.713	25.8	0.38	350	5.542	1901.022	215.4	0.10
170	2.692	1903.872	24.8	0.38	360	5.700	1901.180	201.8	0.12
180	2.850	1904.030	23.8	0.39					

ON THE PROGRESS MADE IN THE LAST DECADE IN THE DETERMINATION OF STELLAR MOTIONS IN THE LINE OF SIGHT.*

By H. C. VOGEL.

After the early attempts at the determination of the component in the line of sight of the motion of the stars by means of the spectroscope, which were made in 1868 by HUGGINS, in London, and in 1871 by myself at Bothkamp, on a few stars, extensive observations of this kind were conducted at the Observatory at Greenwich, extending over a period of thirteen years. The great persistence exhibited by MAUNDER in these observations, which were placed in his charge, is worthy of the more recognition in view of the slight interest which astronomers then generally had in the physical side of astronomy, and especially in view of their skeptical attitude toward the application of the

*Reprinted from the *Astrophysical Journal* for June, 1900.

spectroscope for determinations of motion. There was, indeed, some basis for this, inasmuch as a contention had arisen among the physicists as to whether the so-called Doppler's principle, which was recognized as experimentally correct for sound-waves, and which also permitted an easy theoretical explanation, could be justifiably transferred directly to light-waves. The striking proofs* of the admissibility of extending Doppler's principle to moving sources of light, furnished by the astrophysicists in the course of time, gradually silenced their opponents, foremost among whom were VAN DER WILLIGEN and SPÉE. We must not omit to mention, however, that an exhaustive theoretical treatment and explanation of the problem has not been given even up to the present time.

The protracted Greenwich observations of the stellar motions, which included forty-eight of the brightest stars, have demonstrated that direct observations with medium-sized instruments cannot furnish results whose uncertainty is of a less order than the average motion of the stars themselves. When the dispersion is just sufficient to permit the definite recognition of the displacement, which at most is slight, the intensity of the spectrum of even the brightest stars in a medium-sized instrument is too low to permit even a tolerably accurate measurement. A further reason for the small success doubtless lay in the unsuitability of the apparatus, which was especially lacking in stability.

When I made the first attempt in 1887, with the assistance of Professor SCHEINER, to record photographically the displacements of the lines in stellar spectra, and then to measure them as accurately as possible on the spectrograms, it very soon appeared that this constituted a very marked advance in the determination of these motions, which are so significant in stellar astronomy. The accuracy of the observations was increased more than eightfold with the apparatus constructed in 1888; the probable error, which in the Greenwich observations averaged $\pm 22^{km}$ for an evening, being brought down in the Potsdam observations to an average of $\pm 2.6^{km}$. We may therefore fairly say that the determination of motions in the line of sight thus first received a substantial basis in the spectrographic method, and thereby the widest prospects were opened for a period of new investigations and discoveries.

*I would refer to the introduction to Part I of Vol. VII of the Publications of the Potsdam Observatory, as well as to DUNÉR'S *Recherches sur la Rotation du Soleil.*

This success is doubtless due in the first instance to the application of photography; but we must not leave out of consideration that it is also in part due to the fact that a complete departure from previous principles was made in the construction of the apparatus, and an instrument was completed exclusively for this definite purpose, possessing the greatest possible stability. While spectroscopes are even yet constructed so that they can serve for many purposes,—permitting variations in the dispersion, and allowing measurements to be made in the most widely separated parts of the spectrum,—the Potsdam instrument photographs only a small portion of the spectrum in the neighborhood of the hydrogen line $H\gamma$. Its dispersion was so chosen that with sufficient sharpness of the spectrum a difference between the setting on a line of the star spectrum and one of the comparison spectrum could be determined under the measuring-machine with an accuracy corresponding to a motion of but a few kilometers. Where the spectrum of the star permitted, it was further arranged so that not only the position of a single line in the stellar spectrum was referred to that of a corresponding line in the comparison spectrum, but several lines were employed for the determination of the displacement. The accurate identification of the lines in the star spectrum was also attempted during the measurement by direct comparison with a plate of the solar spectrum.

I can restrict myself to these general statements, since the apparatus, as well as the methods of measuring the plates and reducing the observations, are sufficiently well known from the full descriptions given in Part I of Volume VII of the *Publications of the Astrophysical Observatory.* But I desire to add something for the accurate description of the state of this branch of science at the conclusion of our series of observations at the beginning of the decade just past, and I also cannot withhold a critique of our observations from the standpoint gained by wider experience.

I would first point out that several of the precautions taken in the observations, which might appear as carried too far, were conditioned by an unsuitable telescope. The Potsdam 11-inch refractor is of very light construction, and has a wooden tube which occasions a strong effect of temperature in the alteration of the focal length. Although the wooden tube is conical, it has a very appreciable flexure.

In consequence of the slight stability of the telescope, an arrangement had to be thought out for bringing the star accurately upon the slit and holding it there in the proper position during the exposure of the photographic plate. This was accomplished by the simple means of simultaneously observing with a small telescope the image of the slit, illuminated by a Geissler tube, and the image of the star, reflected from the front face of the first prism. This method of guiding appears to have been adopted later by all observers who have undertaken determinations of velocities by the spectrographic method.

It is no longer indispensable with some of the more recent instruments, as for instance the great Potsdam refractor, since a guiding telescope of nearly the same focal length is attached to the telescope itself.

Although it was my endeavor to develop something entirely new in constructing the stellar spectrograph in 1888, in respect to the prisms I was under the influence of the times, and chose the compound prisms known as Rutherfurd's, which then were considered the most excellent, and in fact possessed the advantage of giving less deviation for the same dispersion, and hence less curvature of the spectral line, and which caused less loss by reflection on account of the less oblique incidence of the rays. Extensive investigations made here at a later time have shown that simple prisms are preferable, and elsewhere the use of prism systems has continually decreased. In observations with the spectrograph we have had the experience that strains occur in the cemented prisms at temperatures below -2°, causing a diffuseness of the spectra. A consequence of the above mentioned large flexure of the wooden tube of the 11-inch refractor may be that in many positions of the telescope the collimator and the prism are not fully utilized; except for a slight loss of light, this would have no injurious effect on the observations under conditions of good adjustment, perfect surfaces of the prisms, and complete homogeneity of the masses of glass used for the prisms.

As above stated, however, tensions in the prisms and consequent departures from homogeneity in the glass have shown themselves distinctly at low temperatures, which have caused not only a diffuseness of the spectra and a consequent diminished accuracy, but also have not been without effect on the displacement of the lines. Although this effect may have been exceedingly slight in most cases, it may nevertheless have become

appreciable in unusual positions of the telescope, such as occur for stars near the pole, and possibly the large discrepancies for a few stars between our observations and those of other observers may be thus explained. In our observations we have always used the telescope in that position only (east or west) in which the optical axis of the collimator and telescope were adjusted. It was not possible to determine subsequently the effect of a lack of coincidence of the two axes on the displacement of lines in the spectra; this, moreover, could hardly have been determined at the time of observation, since it depends on the changes of temperature in the prisms, and the tension thereby occasioned, as well as upon the declination and the hour-angle. The determination of the true temperature of the prisms is in general beset with difficulties, and the determination of the temperature of the separate parts of the prisms is, therefore, hardly to be thought of. We might infer that the errors arising would balance each other in a great number of observations made under the greatest variety of conditions. It would, however, probably be possible to obtain later data as to the errors dependent upon the position of the spectrograph, from a comparison of the Potsdam observations with the results obtained by other observers and with other instruments.* Such errors are hardly to be expected in the newer instruments with simple prisms, and having greater stability of the telescope. We have most carefully studied the effect of the temperature on the focal length of the objective of the refractor and upon the focal length of the objectives of the collimator and camera, as well as the varying dispersion of the prism with the temperature, and we have taken them into account both in the observations and in the reductions of the measures.

The hydrogen spectrum was in nearly all cases used as a comparison spectrum, though attempts were made to use the

---

* At present I am acquainted with determinations of the motions of only something more than half of the objects observed in Potsdam, made by BÉLOPOLSKY, CAMPBELL, NEWALL, and LORD, for the great part of which I am indebted to letters of Messrs. BÉLOPOLSKY and CAMPBELL. The comparison of these with the Potsdam observations leads to the following provisional results. The departure of the Potsdam results from those of the above observers averages $\pm 2.8^{km}$ for 23 objects, and the comparison shows with some certainty that the Potsdam values on the average are 1.2^{km} too large for stars of negative motion, and 0.7^{km} too small for those of positive motion. This constant departure is more clearly pronounced if we consider CAMPBELL's observations only. Taking the mean from 19 objects the departure V. S. — C. = $\pm 2.7^{km}$; the negative velocities were found on the average to be 2.5^{km} larger and the positive velocities 1.6^{km} smaller by VOGEL and SCHEINER than by CAMPBELL. If we apply these average values to the observations, the mean value of the difference V. S. — C. comes out as $\pm 2.0^{km}$.

magnesium line λ 448 $\mu\mu$, which possesses the advantage of being very sharp in some star spectra, while the $H\gamma$ line is broad and diffuse; but without success, since this line is diffuse in the spark spectrum. The iron spectrum may also be used, and I have pointed out the advantages gained in the use of this spectrum, as well as that of other metallic substances, have described the method of observation, and have illustrated it by an example — the spectrum of *Sirius.** It would have been better for this purpose to have used the spectrum of *α Cygni* or of a star of the second class, because the lines in the spectrum of *Sirius* are exceedingly fine. For *Sirius* the probable error of the motion in the line of sight obtained from the difference between a single line in the star spectrum and a single line in the comparison spectrum is $\pm 1.34^{km}$; so by the use of nine such pairs the probable error of the measurements of the plate would not be more than $\pm 0.45^{km}$.

The observations could be made on only forty-seven of the brighter stars, since the spectrum of a star fainter than 2.3 magnitude with an exposure of about an hour did not have sufficient intensity to be measured with accuracy. With a longer exposure the practically unavoidable changes in temperature produced such an influence on the spectrograph that the accuracy of the observation was impaired. As a guard against accidental errors, it was intended that each star should be observed on at least two nights. At the time when these observations were begun, the possibility that a star might show changes in its motion in the line of sight, in a short time, had not been thought of; yet out of these forty-seven stars four had already been found to have a periodic variation during the progress of the work.

The object of this work on the motion of stars in the line of sight, completed in 1891, was first to demonstrate the usefulness of the spectrographic method for instruments of medium size, and further, by means of a thorough and detailed description of methods, to enable an observer equipped with better instruments to carry on observations of this character; and possibly to give the method still further development. There was no need of our repeating these observations in the next few years with the same instrument, while we hoped that in the near future we should be able to extend them with more powerful optical means. Unfortunately the realization of this hope was deferred from

* *Sitz. d. k. Acad. d. W. Berlin*, No. 28, 533, 1891.

year to year, and not until the present year did it again become possible for us to carry on regular observations at the Potsdam Observatory — this time, however, with instruments of the highest order of excellence.

Now, while the seed which we planted ten years ago has not hitherto received in Potsdam the nourishment which we could have wished, yet I have the pleasure of knowing that it has found nourishment in other places, so that it has thriven greatly, and has already blossomed beyond our highest expectations.

In 1890 and 1891 KEELER made his beautiful observations on the radial velocity of the brighter nebulæ, by means of a grating spectroscope attached to the great refractor of the Lick Observatory. Fourteen nebulæ were examined for motion, and the determinations of these motions are of remarkable accuracy, considering the great difficulty of the observations. The probable error of the result for each nebula, a result which is the mean of several observations, is on the average only $\pm$ 3.2^{km}. Of the fourteen nebulæ, nine have a negative and five a positive motion, referred to the Sun. The average motion is 27^{km}, and therefore, if we are justified in drawing a conclusion from so small a number of observations, is of the same order as that of the brighter stars. The greatest velocity, — 65^{km} per second, is that of the well-known planetary nebula *G.C.* 4373, H IV 37. It exceeds by about 10^{km} that of α *Tauri*, which has the greatest velocity of any of the brighter stars of the northern heavens.

While making these observations on nebulæ, KEELER determined the radial velocities of α *Bootis*, α *Tauri*, and α *Orionis*. He found for the velocity of α *Bootis*, from nine measures during 1890 and 1891, a value of — 6.8^{km} $\pm$ 0.3^{km}; for α *Tauri*, on three evenings, + 55.2^{km}, and for α *Orionis*, on two evenings + 14.0^{km} per second. The probable error of a single evening's observations, deduced from the results for the three stars, averages $\pm$ 1.8^{km}.

The Potsdam observations made from 1888 to 1890 give for these three stars the values: — 7.6 $\pm$ 0.6^{km}, + 48.5^{km}, and + 17.2^{km}. A better agreement, considering the complete independence and entirely different character of the methods used (KEELER made his measures on the D lines), could hardly be expected. With the Lick refractor, which exceeds the Potsdam

11-inch refractor some eight times in light-gathering power, it has therefore been possible to determine the motions of the brighter stars, by direct observation, with about the same accuracy as with the Potsdam refractor by the spectrographic method.

About the end of the year 1891, the great Pulkova refractor of 76^{cm} aperture was provided with a spectrograph, built exactly according to the model of the Potsdam instrument, and like the latter provided with two Rutherfurd prisms. The instrument was so arranged that the prism-box could be removed, and another, containing only a single prism, substituted for it when faint objects were to be observed with small dispersion. Since the refractor had been intended primarily for micrometric work, and only secondarily for spectroscopic, the telescope and observing-chair had been designed mainly with reference to the convenience of the observer at the micrometer. For this reason BÉLOPOLSKY had to contend with many difficulties before he finally succeeded, after making a number of considerable changes in the telescope and the observing-chair, in making spectrographic observations with accuracy. The very unsuitable climate made it necessary for him to abandon his original plan of observing the motions of the fainter stars, a plan which may be regarded as an extension of the Potsdam observations. He therefore selected special objects from among the variable and double stars for his observing-list, and made observations of their motions.

Among his valuable researches should be mentioned his investigations of δ *Cephei**, in which he demonstrates the existence of a periodical variation in the velocity of this star in the line of sight, which could be brought into good agreement with the period of its light curve, $5^d\ 9^h$. In the case of η *Aquilæ*† he discovered a variation in the velocity which found an explanation in the period of light-variability of $7^d\ 4^h$; and finally he found a change in the velocity of α^1 *Geminorum*‡ with a period of $2^d\ 23^h.5$. It soon appeared that the line of apsides of this double-star system was in rapid revolution, and from careful investigation the period of this motion was found to be 4 years 40 days.§

As the interesting double spectrum of the well-known variable β *Lyræ* was known, from spectrographic observations, to contain pairs of bright and dark lines, and since changes in the relative

* *Astrophysical Journal*, Vol. 1, 160. *A. N.*, Vol. 140, 17.
† *Mem. Spettr. Ital.*, Vol. 26, 101.
‡ *Bull. Acad. St. Petersbourg*, No. 4, 341. *Astrophysical Journal*, Vol. 5, 1.
§ *Mem. Spettr. Ital.*, Vol. 26, 101, and Vol. 28, 103.

positions of these lines had been discovered which were connected in some way with the period of variability of $12^d.9$, PICKERING attempted to calculate the orbit of this hypothetical double star from measures of the distances between the double lines at different phases of the light period. He found a relative velocity of the components of 482^{km} per second, and a diameter of the orbit, assuming it to be circular, of 85.3 million kilometers. I have more recently pointed out that the distance between the lines, and therefore the relative velocity of the components, has been taken to be too large, by not taking into account a probable overlapping of the lines; since the above value leads to an enormous mass (150☉) of the system. BÉLOPOLSKY has published an extensive investigation* of *β Lyræ*, based on observations made with the Pulkova refractor, in which are contained many interesting details concerning the changes which take place in the pairs of bright and dark lines during the period of the star's variability. From his measures of the hydrogen line $H\beta$ he found an orbital velocity of 89^{km} per second, a semiaxis of 15 million kilometers, and hence a mass of the system of the same order as that of the Sun.

In 1894, while examining a large mass of observations of *β Lyræ* made with a small single-prism spectrograph attached to the photographic refractor of the Potsdam Observatory,† I found clearly a certain agreement between the relative displacement of the lines and the period of light variability, but not of the simple character assumed by BÉLOPOLSKY. The variation in the distance between the bright and dark line $H\zeta$, especially, seemed to correspond to a period much longer than the period of the light variation, so that a system of two bodies was no longer adequate to explain the phenomena observed in the spectrum. Now since it has been shown by MYERS that the light curve is very satisfactorily represented under the assumption of a double-star system, we are compelled to introduce explanations which depend upon phenomena of a physical nature.

BÉLOPOLSKY‡ thereupon, in 1897, resumed his investigations, and from them there is no doubt that we have come nearer to a decision as to the nature of *β Lyræ*. In his measures he disregarded the bright lines altogether, and restricted himself to the

---

* *Bull. Acad. St. Petersbourg*, N. S., No, 4, 341. *Mélanges mathem. et astr.*, Vol. VII. Livr. 3, 1893.

† *Sitz. d. K. Akad. d. W. Berlin*, 1894, 115.

‡ *Mem. Spettr. Ital.*, Vol. 26, 135; also Tikhoff, *ibid.*, Vol. 26, 107.

dark magnesium line λ 448 $\mu\mu$, which has no companion emission line, and thus freed them from the influence of a partial overlapping. By so doing he was able to obtain results which were referable to the case of a simple double star without further complication. He found for the orbital velocity 178^{km} per second, for the semiaxis of the orbit 31.9 million kilometers for the distance between the two components 47.5^{km}, and for their masses respectively 9 and 18 times the Sun's mass.

BÉLOPOLSKY has also found variable motion in λ *Tauri*, ζ *Geminorum*, and θ *Ursæ Majoris*,* so that his contribution to the discovery of spectroscopic binaries consists of seven objects.

It is of interest to note here the great velocity of -70^{km} per second, referred to the Sun, which BÉLOPOLSKY has found for ζ *Herculis*.† CAMPBELL,‡ at the Lick Observatory, has confirmed this observation and obtained a value of -70.3^{km}, while DESLANDRES,§ at Paris, obtained a value about 10^{km} smaller. In this connection I may remark that CAMPBELL has found in η *Cephei* the greatest known velocity of a star in the line of sight (-87^{km} per second). This velocity would probably be reduced somewhat if we were to take into account the motion of the solar system. Assuming the co-ordinates of the apex of the Sun's way to be $\alpha = 267°$ and $\delta = +31°$, and the velocity of the Sun to be 17^{km} per second, we get for the absolute component of the velocity in the direction of the Sun, -74^{km} per second for η *Cephei*, -54^{km} for ζ *Herculis*, and -51^{km} for the nebula *G. C.* 4373.

In publishing his observations of ζ *Herculis*, DESLANDRES made a remark concerning the Paris telescope of 1.2 meters aperture, to which his spectroscope was attached, from which it appears that the stability of the telescope is hardly what it should be for such delicate investigations; and, possibly because the mirror did not unite perfectly all the rays on the slit, the exposure had to be made 50 per cent. longer than with the Pulkova refractor, under presumably less favorable atmospheric conditions. In these unsuitable conditions may also be found the reason why so few observations of stellar motion by DESLANDRES have been made known. He has published beautiful threefold enlargements of the original spectrograms ‖ of the four stars α *Aurigæ*, β *Aurigæ*, α *Canis Majoris*, and γ *Pegasi*, which are

* *A. N.*, Vol. 145, 281; also Vol. 149, 239, and Vol. 151, 39.

† *A. and A.*, February, 1894. *A. N.*, Vol. 133, 257.

‡ *Astrophysical Journal*, Vol. 8, 157. § *C. R.*, Vol. 119, 1252.

‖ *Spécimens de Photogr. Astronomiques. Obs. de Paris*, 1897.

specially remarkable for the great length of spectrum which his apparatus is capable of defining sharply. With the exception of a series of observations of α *Aquilæ*, nothing further is known to me of work on the motions of stars at the Paris Observatory.

At the suggestion of POINCARÉ of Paris, DESLANDRES has, on the other hand, made spectrographic researches on the motion of the planets, and on the rotation of *Jupiter*,* which are of importance. The investigations showed, in accordance with POINCARÉ'S assumptions, that in the case of a body which shines by diffuse reflected light, the displacement of lines in its spectrum depends not only on the motion of the body with reference to the observer, but also on the motion of the body with reference to the source of light by which it is illuminated.† The observations on the rotation of *Jupiter* have been repeated and confirmed by BÉLOPOLSKY.

The beautiful results which KEELER obtained by the spectrographic method at the Allegheny Observatory on the rotation of the ring system of *Saturn*, should be mentioned in this connection. By these observations it was shown that *Saturn's* rings consist of separate small bodies which revolve about *Saturn* in obedience to KEPLER'S laws, and cannot be regarded as a rigid body, thus furnishing a practical confirmation of the conditions demanded by theory.‡ These interesting observations have been repeated by CAMPBELL, BÉLOPOLSKY, and DESLANDRES.

The first attempts to prove the truth of Doppler's principle, by showing that there is a displacement of the lines in the spectrum of the edge of the Sun near the equator which corresponds to the known equatorial velocity obtained from observations of sun-spots, were made by me twenty-nine years ago. In the course of time these observations have been frequently repeated with improved instruments. DUNÉR, in Lund, has undoubtedly carried out the most thorough investigation of the rotation of the Sun in different zones, by means of spectroscopic methods.§

* *C. R.*, Vol. 120, 417. † *A. N.*, Vol. 139, 241.

‡ KEELER used in these observations a spectrograph composed of three simple prisms, which produced a total deviation of 180°. From a few original negatives of the solar spectrum and several excellent negatives of planetary spectra, which he kindly sent me, I was able to see that the apparatus is very similar to the Potsdam spectrograph of 1888, both as regards dispersion and resolving power. The dispersion of KEELER'S apparatus is about one-twentieth greater than that of the Potsdam spectrograph, while the resolution of close lines is almost exactly the same in both instruments. Perhaps KEELER'S apparatus is slightly superior to the Potsdam apparatus in this respect.

§ N. C. DUNER: "Recherches sur la Rotation du Soleil." *Nova Acta Reg. Soc. Sc. Ups.* Series III.

He was induced to make these observations because, in the beginning of the 'eighties, the trustees of the Lars Hjertas Minne endowment expressed a desire to have the spectroscope used for a careful investigation of the question whether the wave-length of light really varies directly as the velocity of the source of light, as required by the Doppler-Fizeau principle, and had expressed their willingness to grant sufficient money for a suitable spectroscope.

To give some idea of the results of his observations, which were made during the summer months of the years 1887, 1888, and 1889, I have inserted the following table of the means for various heliocentric latitudes, with their probable errors:—

Heliocentric latitude.	Velocity in km.	Number of observations.	$\xi \cos \phi$	ξ
0°.4	1.98 ± 0.013	107	14°.14	14°.14
15 .0	1.85 0.013	104	13 .19	13 .66
30 .0	1.58 0.014	104	11 .31	13 .06
45 .0	1.19 0.014	106	8 .48	11 .99
60 .0	0.74 0.012	107	5 .31	10 .62
74 .8	0.34 0.013	107	2 .45	9 .34

Shortly before the completion of DUNÉR'S researches there appeared two extended investigations by CREW† on the same subject, which led to the result that the absorbing layer of the Sun rotates with a uniform angular velocity, while DUNÉR'S observations cannot be harmonized with the assumption of a constant angular velocity, as is shown by the table, in which the angular velocity (ξ and $\xi \cos \phi$) is given in the last two columns. This is not the place to discuss the difference between the results obtained by the two observers; for it was merely my purpose to mention the beautiful observations which have been made in this field, and to show what great accuracy can be given to spectroscopic observations of motion when there is sufficient light. The observations of DUNÉR agree very well with the law of the rotation of the Sun derived from the observations of the sun-spots.

With regard to the above-mentioned desire of the trustees to ascertain whether the change in the wave-length of light is proportional to the velocity of the luminous source, DUNÉR'S observations have shown that, within the errors of observation, the simple form of Doppler's principle is valid, and the influence of possible higher terms is not recognizable.

† HENRY CREW: "On the Period of the Rotation of the Sun as Determined by the Spectroscope." *Am. Jour. Sci.*, Vol. 35, 151, and Vol. 38, 204.

Through the generosity of Mr. D. O. MILLS, Professor HOLDEN, at that time Director of the Lick Observatory, was able to have a spectrograph constructed for the Observatory about the middle of the nineties, to be used exclusively for determining stellar motions in the line of sight. In the October, 1898, number of the *Astrophysical Journal*, Professor CAMPBELL has given an extended description of this instrument, which mainly through his endeavors has become the most noted instrument of its time.

Attached to the great 36-inch refractor of the Lick Observatory, used under the most excellent atmospheric conditions, and in the hands of a circumspect and careful observer, the Mills spectrograph has in the last few years achieved surprising results. The spectrograms taken with it possess, on the average, a sharpness which excels that of even the best spectrograms taken with the Potsdam apparatus of 1888, and the resolving power of the instrument is much greater. Through the kindness of Messrs. KEELER and CAMPBELL, I received last year two original negatives, one of γ *Andromedæ*, and the other of η *Pegasi;* so that I was able to thoroughly assure myself of their excellence. They are marked as being above the average excellence, and their measurement is a real pleasure; yet even with such plates great care and long experience are required to obtain uniformly consistent results.

With spectra which contain many lines, and which differ considerably from the solar spectrum, the use of a solar spectrum in measuring the plates cannot well be avoided. In many spectra, on the other hand, especially those with strong iron lines, the stellar and comparison spectra can be compared directly by means of HARTMANN'S interpolation formula.* The amount of the shifting of a known line in the star spectrum can be exactly determined even if there is no identical line in the comparison spectrum; for instance, the lines of hydrogen and clèveite gas can be compared with iron lines in the comparison spectrum.

On CAMPBELL'S plates the probable error of the determination of the distance between a stellar line and the corresponding comparison line may be taken as $\pm$ 1.2^{km}, and since from ten to twenty measurable lines may easily be found in the spectrum of a star of class II, the probable error of the mean of the measures on a single plate may be reduced to about $\pm$ ⅓^{km}. Slight

**Publ. des Astrophys. Obs. zu Potsdam,* Vol. 12, No. 42.

changes in the instrument during the exposure, slight differences in the observer's habit of measurement, minute distortions of the film, and other unavoidable sources of error have here to be taken into account. They are recognizable in the fact that the probable error of the final result, deduced from the mean of several plates of the same object, is larger than that which the probable error of a single plate, determined from the agreement of the different lines, would lead one to expect. According to CAMPBELL'S observations of the brighter stars, the probable error of a single plate is, however, somewhat less than $\pm 1^{km}$. CAMPBELL'S detailed description of the Mills spectrograph, and the opportunity I have had of examining some of the spectrograms made with it, have been of great service to me, since the new spectrographs for the large Potsdam refractor, which have been made from my designs by TOEPFER, of Potsdam, were just at that time so nearly completed that they could be subjected to a preliminary test. The construction of these two spectrographs was begun in 1897. One of them has three simple prisms, and a total deviation of 180°, while the other has only one simple prism. Dr. HARTMANN, whom I had commissioned to make the adjustments and tests of the optical parts of these spectrographs, has devoted all his energies to obtaining the highest degree of excellence,* and it is a pleasure to be able to say that the new spectrograph with three prisms for the Potsdam 80^{cm} refractor will not be inferior to the Mills spectrograph.

At the present time a series of observations of the radial velocities of stars down to the fifth magnitude is being made at the Lick Observatory. So far Professor CAMPBELL has made two or more observations on about 300 stars, and has found 16† of them to have a variable velocity, thus bringing the number of binaries discovered by spectrographic methods up to 28. I shall merely give here a list of the spectroscopic binaries discovered by CAMPBELL.‡

Star.	Period.
η *Pegasi*	2¼ years.
χ *Draconis*	9⅓ months.

* For particulars on this investigation, and the methods used in testing, see Dr. HARTMANN'S paper in *Astrophysical Journal* for June, 1900, and following numbers.

† Since the annouucement of these sixteen spectroscopic binaries, the observations with the Mills spectrograph have led to the discovery of thirteen additional systems; placing the total for the Lick Observatory at twenty-nine.—*Pub. Com. A. S. P.*

‡ *Astrophysical Journal*, Vols. 8, 9, 10.

o *Leonis*	14½ days.
ζ *Geminorum*	Unknown.
ι *Pegasi*	Over 10 days.
θ *Draconis*	Over 9 days.
ϵ *Libræ*	Unknown, several months.
β *Capricorni*	Unknown, long.
h *Draconis*	Undetermined.
λ *Andromedæ*	About 20 days.
ϵ *Ursa Minoris*	A few weeks.
ω *Draconis*	Unknown.
α *Ursa Minoris*	3 9 days and a second longer period.
α *Aurigæ*	3½ months.
v *Sagittarii*	A few weeks.
β *Herculis**	Unknown, 1 year?

It is worthy of remark that several stars have a period of many months, and that η *Pegasi* has a period of 2¼ years. Thus the gap which formerly existed between the spectroscopically discovered and the visual double stars, with respect to the lengths of their periods of revolution, has been filled up.

When we consider the large number of variable stars of the *Algol* type which have been discovered photometrically during the last decade, and for which the assumption appears to be justified that their variation is a consequence of duplicity; when we further consider that these stars can be recognized as variable only when the line of sight makes an extremely small angle with the plane of the orbit, and that for the spectroscopically discovered stars, also, this angle cannot be supposed to be very great, we cannot repress our astonishment at the rapidity with which the number of stars thus discovered has grown.

Among the double stars discovered at the Lick Observatory, *Polaris*, which has a double period of motion in the line of sight, is of particular interest, since we are here led to infer the existence of three bodies. The discovery of the short period is an admirable proof of the excellence of the observations, since the variation from the mean velocity is only $\pm 3^{km}$.

Of particular interest, also, is the discovery of the periodic doubling of the lines in the spectrum of α *Aurigæ*, which consists of two superposed spectra uniting at times to form a spectrum strongly resembling that of the Sun.† Although α *Aurigæ*

---

* *A. S. P.*, Vol. 12, 39, 1900.

† From CAMPBELL'S observations the deduction can also be made that both stars, one having a spectrum similar to the solar spectrum, and the other a spectrum containing the hydrogen and the stronger iron lines, are of nearly the same mass, since their dis-

was frequently observed at Potsdam during the years 1888–1891, this peculiarity of its spectrum escaped us, and the explanation of the fact that most of our spectrograms of α *Aurigæ* are ill-defined and the lines quite extraordinarily broadened, was only given later, by the investigations of CAMPBELL. The days on which the spectrograms obtained were good and sharp, are those on which the two spectra were superposed, and our early observations have now at least given us the means of arriving at a more accurate value of the period ($104^d.1 \pm 0^d.2$). By means of observations with the new Potsdam refractor and spectrograph, we have been able to confirm CAMPBELL'S observations, both of α *Aurigæ* and α *Ursæ Minoris.**

When we consider that researches on the motions of stars in the line of sight have been begun and are being carried on with good results by NEWALL, in Cambridge, and by LORD, at the McMillin Observatory in Ohio; that in Meudon a double refractor of the same size as the Potsdam instrument has been set up, and provided with a spectrograph, with which DESLANDRES† has already succeeded in showing that δ *Orionis* is a star with variable velocity; that further, the largest instrument in the world, Yerkes refractor at Williams Bay, will also be used for this purpose, and that GILL, with the double refractor of the observatory at the Cape of Good Hope, will extend the same researches to the southern heavens, we may confidently expect that our knowledge of the stellar system to which we belong will be increased as much in the new century upon which we are entering as our knowledge of the solar system has been increased in the century just past. The energy with which some of the largest observatories in the world are participating in the work is most encouraging, for the amount of work to be done has grown most unexpectedly during the last decade, through the discovery of so many stars having a variable velocity in the line of sight.

In closing this review, I should not wish to leave unmentioned the fact that in one case the application of the Doppler-Fizeau principle can no longer be regarded as valid; I refer to the

placements from the mean position are about equal. Assuming the period to be $104^d.1$ and the maximum relative velocity to be $\pm 30^{km}$, and assuming provisionally that the orbit is nearly circular, with its plane in the line of sight, I have found, for the combined mass of the stars, $m+m_1,=2.3\,\odot$, and for their distance, 85.3 million ^{km}.

* It should be added here that the discovery of the duplicity of the lines of α *Aurigæ* was made independently, and almost simultaneously, by NEWALL, of Cambridge, England.

† *C. R.*, Vol. 130, No. 7.

interpretation of the pairs of bright and dark lines which are found in the spectra of the new stars. When this peculiarity of the spectra of new stars was discovered, it was very natural that the relatively strongly displaced emission and absorption lines should be ascribed to the spectra of two bodies, whose motions in the line of sight were oppositely directed. Corresponding to the great displacement of the lines, velocities were arrived at which, in comparison with the mean velocity of other heavenly bodies whose motions have been spectroscopically determined, must be characterized as perfectly enormous — more particularly since it was improbable that the whole motion of the bodies should be in the line of sight.

But since in the stars which have appeared more recently, *Nova Normæ* and *Nova Carinæ*, the same pairs of bright and dark lines were found, in which, as in the spectrum of *Nova Aurigæ*, the emission line lay on the less refrangible side; and since similar lines can be observed in the spectra of *β Lyræ* and *P Cygni* (the *Nova* of 1600); and particularly since no change in the distance between the bright and dark lines could be detected during the whole of the first apparition of *Nova Aurigæ*, and the lines remain unchanged in position in the spectrum of *P Cygni* — while in *β Lyræ*, though they vary during the star's period, the changes are never so great as to reverse the positions of the dark and bright lines — doubts as to the applicability of Doppler's principle to such cases appeared to be more and more fully justified.

The assumption that we are here concerned with phenomena of a purely physical nature gained a firmer basis through the researches of HUMPHREYS and MOHLER, EDER, and WILSING,* on the changes produced in spectral lines by high pressure. It was found that under high pressure pairs of bright and dark lines could be produced in metallic spectra, in which the emission line always lay on the less refrangible side.

These observations are to be regarded as only first beginnings; but doubtless through them a wide field of highly interesting research is opened, in which the astronomer may hope for the zealous support of the physicist. The veil which has enveloped anew our knowledge of the nature of the temporary stars will certainly be lifted, when experiment shall yield results which

* "Ueber die Deutung des typischen Spectrums der neuen Sterne." *Sitz. d. K. Akad. d. W. Berlin*, Vol. 24, 425. 1899.

harmonize with the phenomena observed in them; and not until then will the time come to frame hypotheses respecting the origin of the abnormal conditions of pressure in their atmospheres.

It is quite possible that, as observations of motions in the line of sight become more and more refined, the conditions of pressure in the atmospheres of the stars can no longer be neglected, although it may be assumed that the pressure in the atmospheric layers from which the light comes to us is neither subject to great variations for any individual star, nor varies widely for different individuals. Even if this should not be true, the means of arriving at accurate results for stellar motion, and at the same time of gaining information concerning the conditions of pressure in the stellar atmospheres, is to be found in the use of different metals for comparison spectra.

THE ORBIT OF *99 HERCULIS* = *A. C.* 15.

By R. G. Aitken.

The faint companion to *99 Herculis* was discovered by Alvan Clark in 1859, and the first measures of it were secured by Dawes in the same year. Otto Struve measured it on five nights during the next twenty years, but otherwise it was wholly neglected until Burnham began work with the 18½-inch Dearborn refractor in 1878.

The measures indicated motion, but whether this was rectilinear or orbital it was impossible to say until 1889. In that year Burnham observed the pair with the 36-inch telescope of the Lick Observatory, and found that the small star had passed over an arc of more than 180° since his observation in 1881. It was at once evident that the system was binary, with a moderately short period.

In the last ten years the star has been observed frequently, but the great difference in the brightness of the two components, and their small angular separation, make it a difficult object, and the measures are discordant.

The following are all the published observations:—